

# Specialists and Generalists: Equilibrium Skill Acquisition Decisions in Problem-solving Populations

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## Abstract

Many organizations rely on the skills of innovative individuals to create value, including academic and government institutions, think tanks, and knowledge-based firms. Roughly speaking, workers in these fields can be divided into two categories: specialists, who have a deep knowledge of a single area, and generalists, who have knowledge in a wide variety of areas. In this paper, I examine an individual's choice to be a specialist or generalist. My model addresses two questions: first, under what conditions does it make sense for an individual to acquire skills in multiple areas, and second, are the decisions made by individuals optimal from an organizational perspective? I find that when problems are single-dimensional, and disciplinary boundaries are open, all workers will specialize. However, when there are barriers to working on problems in other fields, then there is a tradeoff between the depth of the specialist and the wider scope of problems the generalist has available. When problems are simple, having a wide variety of problems makes it is rational to be a generalist. As these problems become more difficult, though, depth wins out over scope, and workers again tend to specialize. However, that decision is not necessarily socially optimal—on a societal level, we would prefer that some workers remain generalists.

*Keywords:* Skill acquisition, specialization, jack-of-all-trades, problem solving, knowledge based production, human capital

*JEL Codes:* J24, O31, D00, M53, I23

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*Thanks to Scott Page and Ross O’Connell. This work was supported by the NSF and the Rackham Graduate School, University of Michigan. Computing resources supplied by the Center for the Study of Complex Systems, University of Michigan.*

# Specialists and Generalists: Equilibrium Skill Acquisition Decisions in Problem-solving Populations

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## 1. Introduction

Many organizations rely on the skills of innovative individuals to create value. Examples include academic institutions, government organizations, think tanks, and knowledge-based firms. Workers in these organizations apply a variety of skills to in order to solve difficult problems: architects design buildings, biochemists develop new drugs, aeronautical engineers create bigger and better rockets, software developers create new applications, and industrial designers create better packaging materials. Their success—and thus the success of the organizations they work for—is dependent on the particular set of skills that they have at their disposal, but in most cases, the decision of which skills to acquire is made by individuals, rather than organizations. The perception is that these workers choose to become more specialized as the problems they face become more complex (Strober (2006)) . This perception has generated a countervailing tide of money and institutional attention focused on promoting interdisciplinary efforts. However, we have very little real understanding of what drives an individual's decision to specialize.

Roughly speaking, workers in knowledge-based fields can be divided into two categories: specialists, who have a deep knowledge of a single area, and generalists, who have knowledge in a wide variety of areas.<sup>1</sup> In this paper, I consider an

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<sup>1</sup>This dichotomy is often summed up in the literature via a metaphor used by Isaiah Berlin

individual's decision to be a specialist or a generalist, looking specifically at two previously unaddressed questions. First, under what conditions does it make sense for an individual to acquire skills in multiple areas? And second, are the decisions made by individuals optimal from an organizational perspective?

Most of the work done on specialists and generalists is focused on the roles the two play in the economy. Collins (2001) suggests that specialists are more likely to found successful companies. Lazear (2004 and 2005), on the other hand, suggests that the successful entrepreneurs should be generalists—a theory supported by Astebro and Thompson (2011), who show that entrepreneurs tend to have a wider range of experiences than wage workers. Tetlock (1998) finds that generalists tend to be better forecasters than specialists. In contrast, a wide variety of medical studies (see, for example, Hillner et al (2000) and Nallamothu et al (2006)), show that outcomes tend to be better when patients are seen by specialists, rather than general practitioners. However, none of this work considers the decision that individuals make with respect to being a specialist or generalist. While some people will always become generalists due to personal taste, the question remains: is it ever rational to do so in the absence of a preference for interdisciplinarity? And is the decision that the individual makes optimal from a societal perspective?

There is evidence that being a generalist is costly. Adamic et al (2010) show that in a wide variety of contexts, including academic research, patents, and contributions to wikipedia, the contributions of individuals with greater focus tend to have greater impact, indicating that there is a tradeoff between the number of fields an individual can master, and her depth of knowledge in each. This should not be surprising. Each of us has a limited capacity for learning new things—by focusing on a narrow field of study, specialists are able to concentrate

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in an essay on Leo Tolstoy: “The fox knows many things, but the hedgehog knows one big thing” (Berlin (1953)) In other words, foxes are generalists with a wide variety of tools to apply to problems (albeit sometimes inexpertly) and hedgehogs are specialists who have a single tool that they can apply very well.

their efforts and maximize the use of that limited capacity, while generalists are forced to spread themselves more thinly in the pursuit of a wider range of knowledge. In the language of economics, generalists pay a fixed cost for each new field of study they pursue, in the form of effort expended learning new jargon, establishing new social contacts in a field, and becoming familiar with new literatures.

Given that it is costly to diversify ones skills, the decision to become a generalist can be difficult to rationalize. In this paper, I examine model in which workers decide whether to be specialists or generalists to explore conditions under which it is rational for an individual to choose to be a generalist. I show that when problems are single-dimensional and there are no barriers to working on problems in other disciplines, the equilibrium population contains only specialists. However, when there are barriers to working on problems in other fields (eg: communication barriers or institutional barriers) then there is a tradeoff between the depth of study of the specialist and the wide scope of problems that the generalist can work on. When problems are relatively simple, generalists dominate because their breadth of experience gives them a wider variety of problems to work on. But as problems become more difficult, depth wins out over scope, and workers tend to specialize.

I then show that the equilibrium decisions reached by individuals are not necessarily socially optimal. As problems become harder, individual workers are more likely to specialize, but as a society, we would prefer that some individuals remain generalists. This disconnect reflects the fact that from a social perspective, we would prefer to have researchers apply the widest possible variety of skills to the problems we face, but individuals internalize the cost of obtaining those skills. Thus, the model predicts that some populations will suffer from an undersupply of generalists. In such populations, it would be socially beneficial to subsidize the acquisition of skills in broad subject areas.

Finally, I consider an extension of the model in which problems have multiple parts. This allows me to consider problems that are explicitly multidisciplinary—that is, when different parts of a problem are best addressed using skills from

different disciplines. I show when problems are multidisciplinary, it is possible to rationalize being a generalist, even when there are no disciplinary boundaries. In particular, when there is a large advantage to applying the best tool for the job, being a generalist is optimal.

## 2. Model

I construct a two period model. In period 1, the workers face a distribution of problems and each worker chooses a set of skills. In period 2, a problem is drawn from the distribution, and the workers attempt to solve it using the skills they acquired in period 1. I will solve for the equilibrium choice of skills in period 1.

Let  $S$  be the set of all possible skills.<sup>2</sup> The skills are arranged into 2 disciplines,  $d_1$  and  $d_2$ , each with  $K$  skills,  $s_{1d}...s_{Kd}$ . An example with six skills arranged into two disciplines is shown in Figure 2.1. A *specialist* is a person who chooses skills within a single discipline. A *generalist* is a person who chooses some skills from both disciplines.

A problem,  $y$ , is a task faced by the workers in the model. A *skill* is a piece of knowledge that can be applied to the problem in an attempt to solve it. Each skill  $s_{kd} \in S$  has either a high probability ( $H$ ) or a low probability ( $L$ ) of solving the problem. I will define a problem by the matrix of probabilities that each

skill will solve the problem. That is,  $y = \begin{bmatrix} y_{11} & y_{12} \\ \vdots & \vdots \\ y_{K1} & y_{K2} \end{bmatrix}$  where  $y_{kd} = H$  if

skill  $k$  in discipline  $d$  has a high probability of solving the problem and  $L$  if it has a low probability of solving the problem. So, for example, if there are two

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<sup>2</sup>Skills are defined as bits of knowledge, tools, and techniques useful for solving problems and not easily acquired in the short run. See Anderson (2010) for a model with a similar treatment of skills.

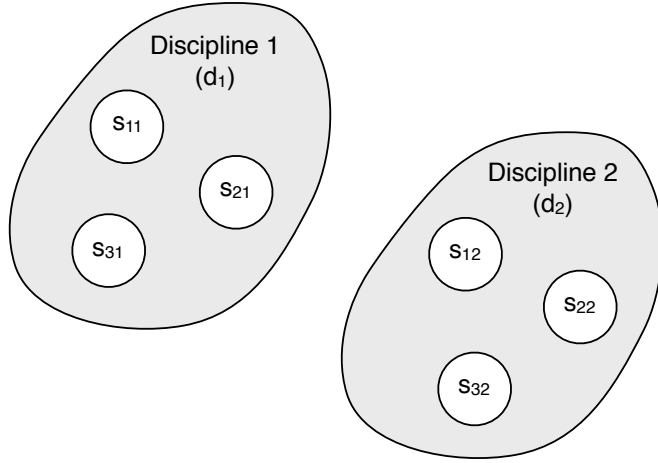


Figure 2.1: Two disciplines, each with three skills.

disciplines, each with three skills, a problem might be

$$y = \begin{bmatrix} L & H \\ H & H \\ H & L \end{bmatrix}$$

meaning that two of the skills in each discipline have a high probability of solving the problem, and one skill in each discipline has a low probability of solving the problem. Define  $h \equiv 1 - H$  and  $l \equiv 1 - L$ .

The mechanics of the model are as follows. In period 1, the workers,  $i_1 \dots i_N$ , each choose a set of skills  $A_i \subset S$ . In period 2, the workers attempt to solve a problem using those skills. I will assume that workers have a *capacity* for learning skills, which limits the number of skills they can obtain. In the current context, I will assume that all workers all have the same capacity for learning new skills, and that all skills are equally costly to obtain.<sup>3</sup> Let  $M \in \mathbb{Z}^+$  represent an individual's capacity for new skills and let  $q = 1$  be the cost of acquiring a

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<sup>3</sup>The case where workers have different capacities would obviously be an interesting extension, as would the case where different skills had different costs.

new skill. I assume that workers pay a fixed cost,  $c$ , for learning skills in a new discipline. That is, a worker pays  $1 + c$  to obtain the first skill in a discipline, and  $q = 1$  for every additional skill in that discipline. For simplicity, I will assume that  $M = K + c$ . This assumption means that a specialist can obtain all  $K$  skills in one discipline, and a generalist can obtain a total of  $K - c$  skills spread over the two disciplines.

Although workers in period 1 do not know the particular problem they will face in period 2, they do know the distribution,  $\Delta$ , from which those problems will be drawn. In particular, they know the probability that each skill will be an H skill or an L skill. For simplicity, I will make two assumptions about the distribution of problems: 1) skills are *independent*, meaning that the probability that skill  $s_{kd}$  is an H skill is independent of the probability that skill  $s_{k'd'}$  is an H skill<sup>4</sup> and 2) skills are *symmetric within disciplines*, meaning that every skill in a discipline has an equal probability of being an H skill.<sup>5</sup>

This knowledge of the distribution of problems can be translated into knowledge about individual skills. Let  $\delta_d$  be the probability that a skill in discipline  $d$  is an H skill—that is,  $\delta_d = E[Prob(y_{kd} = H)]$  where the expectation is taken over the distribution of problems,  $\Delta$ . The vector of probabilities in the two disciplines,  $\delta = [\delta_1, \delta_2]$ , is known *ex ante*.

Workers choose their skills in period 1 to maximize their expected probability of solving the problem in period 2. A Nash equilibrium of this game is a choice of skill set for each worker in the population,  $A = \{A_1 \dots A_N\}$ , such that no worker has an incentive to unilaterally change her skill set, given the distribution of problems.

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<sup>4</sup>This assumption means that skills must be applied more or less independently. That is, it cannot be the case that skills are used in combination to solve problems, or that skills build on one another.

<sup>5</sup>This assumption simplifies the decision making process for generalists. When skills are symmetric within a discipline, a generalist's skill acquisition decision is simply a division of her skills across the two disciplines—within a discipline, she can choose her skills at random.



### 3. Results: Specialization and Barriers Between Disciplines

In this section, I consider two questions. The first question concerns individual decision-making—what is the equilibrium skill acquisition decision of the workers? Under what conditions do individuals decide to generalize? The second question concerns the optimality of that population from an organizational perspective. Is the equilibrium population optimal?

Note that in order to simplify the exposition, I will consider a special case where all disciplines are equally useful in expectation—that is, where  $\delta_1 = \delta_2 = \delta$ . It is straightforward to generalize the results to a case where  $\delta_1 \neq \delta_2$  (see Appendix for the details).

#### 3.1. Equilibrium Skill Populations with No Barriers between Disciplines

Given that generalists pay a significant penalty for diversifying their skills, it is difficult to explain the existence of generalists in the population. Theorem 1 states that if workers can work on any available problem, then there will be no generalists in equilibrium.

**Theorem 1.** *If skills are independent and symmetric within discipline, and workers can work on any available problem, then no worker will ever want to be a generalist and the equilibrium population will contain only specialists.*

*Proof.* The *ex ante* probability that a specialist in discipline  $i$  will be able to solve a problem from a given distribution,  $\Delta$ , is

$$\begin{aligned}
 E[P(S_i)] &= \sum_y \text{Prob}(\text{one of skills solves } y) * \Delta(y) \\
 &= \sum_y (1 - \text{Prob}(\text{none do})) * \Delta(y) \\
 &= 1 - \sum_{n_i=0}^K h^{n_i} l^{K-n_i} \binom{K}{n_i} \delta^{n_i} (1-\delta)^{K-n_i} \\
 &= 1 - (\delta h + (1-\delta)l)^K
 \end{aligned}$$

where  $n_i$  is the number of  $H$  skills in discipline  $i$  in a particular problem,  $y$ .

Now, consider a generalist who is spreading his skills across both disciplines. The *ex ante* probability that a generalist with  $x$  skills in discipline 1 and  $K - c - x$  skills in discipline 2 will solve a problem from a given distribution,  $\Delta$ , is

$$\begin{aligned} E[P(G)] &= 1 - \sum_y \text{Prob}(\text{none of skills solve } y) * \Delta(y) \\ &= 1 - (\delta h + (1 - \delta) l)^{K-c} \end{aligned}$$

$1 - (\delta h + (1 - \delta) l)^K > 1 - (\delta h + (1 - \delta) l)^{K-c}$ , and thus no individual will ever be a generalist in two disciplines. (See Appendix for the same result with  $\delta_1 \neq \delta_2$ )  $\square$

Note that this result generalizes to a case with more than two disciplines. Generalists do worse as they add skills in additional disciplines, so this result holds regardless of the number of disciplines a generalist spreads himself across.

### 3.2. Equilibrium Skill Populations with Barriers between Disciplines

Theorem 1 clearly indicates that when workers can solve problems in other fields, there is no advantage to being a generalist. However, in practice, there may be many barriers between disciplines that prevent a worker in one discipline from solving problems in another. Cultural or institutional barriers may prevent her from working on questions in other disciplines, either because resources are not forthcoming or because it is difficult to get compensated for work in other areas. Communication barriers are also a significant impediment to interdisciplinary work—although a software engineers may have skills useful in solving user interface problems, field-specific jargon may make it difficult for her to communicate her insights. If communication barriers are severe enough, she may even have difficulty understanding what open questions exist. Finally, a person in one field may simply be unaware of problems that exist in other fields, even if her skills would be useful in solving them.

Barriers to working on problems outside ones discipline give us the ability to talk about the “scope” of a worker’s inquiry. Generalists are able to work on a broader set of problems, and thus their scope is larger than that of specialists.

There is therefore a tradeoff between the depth of skill gained through specialization and the scope gained through generalization. A specialist has a depth of skill that gives her a good chance of solving the limited set of problems in the area she specializes in. Generalists have a limited number of skills, but are able to apply those skills to a much broader set of problems. Thus, the choice between being a specialist and a generalist can be framed in terms of a tradeoff between the depth of one's skill set and scope of one's problem set.

More formally, choice of whether to specialize will depend on two parameters. First, let  $\pi(\delta, h, l) \equiv (\delta h + (1 - \delta)l)$  be the expected probability that a skill won't be able to solve a problem drawn from  $\Delta$ . When  $\pi$  is large, the probability that any one skill will solve the problem is very low. Thus, we can think of problems becoming more difficult as  $\pi$  increases. Second, let  $\phi$  be the fraction of all problems that occur in discipline 1. When  $\phi$  is very large or very small, most of the problems fall in one field or another, limiting the value of increasing the scope of the problem set.

These two parameters— $\phi$  and  $\pi$ —define a range in which workers will choose to generalize in equilibrium. This range is illustrated in Figure 3.1. This diagram illustrates the tradeoff between depth and scope. When problems are easy to solve, scope is more valuable than depth. However, as  $\pi$  increases and problems become more difficult, depth wins out over scope, and the range in which individuals choose to generalize shrinks.

Theorem 2 summarizes these results.

**Theorem 2.** *If skills are independent and symmetric within discipline, and there are barriers to working on problems in other disciplines, then workers will generalize if  $1 - \left(\frac{1 - \pi^{K-c}}{1 - \pi^K}\right) \leq \phi \leq \frac{1 - \pi^{K-c}}{1 - \pi^K}$  where  $\phi$  is the fraction of problems assigned to discipline 1. If  $\phi > \frac{1 - \pi^{K-c}}{1 - \pi^K}$ , then workers will all specialize in discipline 1 and if  $\phi < 1 - \left(\frac{1 - \pi^{K-c}}{1 - \pi^K}\right)$  then workers will all specialize in discipline 2.*

*Proof.* In this case, the *ex ante* probability that a problem is solved by a specialist is  $\phi \left(1 - (\delta h + (1 - \delta)l)^K\right)$  for a specialist in discipline 1 and  $(1 - \phi) \left(1 - (\delta h + (1 - \delta)l)^K\right)$

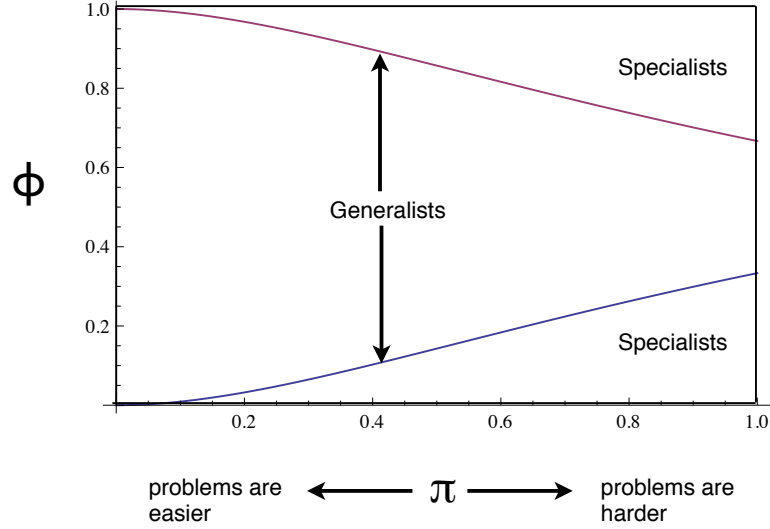


Figure 3.1: Equilibrium skill acquisition decisions when  $k = 3$  and  $c = 1$ .

for a specialist in discipline 2. Since generalists can work on problems in both disciplines, their expected probability of solving the problem is  $1 - (\delta h + (1 - \delta) t)^{K-c}$ . A worker will generalize if  $E[P(S_1)] < E[P(G)]$  and  $E[P(S_2)] < E[P(G)]$ . The result follows immediately. (See Appendix for the same result with  $\delta_1 \neq \delta_2$ )  $\square$

Note that the size of the regions in which workers specialize depends on how costly it is to diversify ones skills. As the fixed cost of learning something in a new discipline increases ( $c \uparrow$ ), the regions in which people specialize grow.

### 3.3. Optimality of the Equilibrium

In this section, I consider whether this distribution of specialists and generalists in the population is optimal, from a societal perspective. There is reason to believe that it would not be. From a societal standpoint, we would like to maximize the probability that someone manages to solve the problem. This means that as a society, we would prefer to have problem solvers apply as wide a range of skills as possible. But workers who diversify their skills obtain fewer

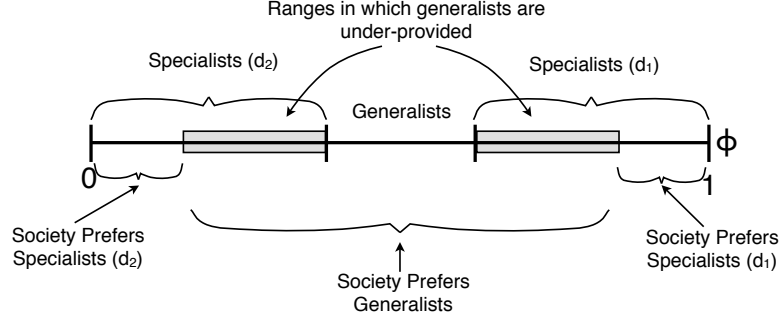


Figure 3.2:

skills overall, which tends to make the individual want to specialize. The result of this disconnect between individual and social welfare is a range in which generalists are under provided (see Figure 3.2). As problems become more difficult, this region of suboptimality grows, as is illustrated in Figure 3.3.

Theorem 3 summarizes these results.

**Theorem 3.** *If skills are independent and symmetric within discipline, and there are barriers to working on problems in other disciplines, then there is a range of values for  $\phi$  (the fraction of problems assigned to discipline 1) such that generalists are underprovided in the equilibrium population of problem solvers.*

*In particular, generalists are underprovided when  $\frac{1-\pi^{K-c}}{1-\pi^K} < \phi < \frac{1-\pi^{N(K-c)}}{1-\pi^{NK}}$  or  $1 - \frac{1-\pi^{N(K-c)}}{1-\pi^{NK}} < \phi < 1 - \frac{1-\pi^{K-c}}{1-\pi^K}$ .*

*Proof.* The probability that at least one of the  $N$  problem-solvers in the population solves the problem is  $1 - \text{Prob}(\text{none of them do})$ . If all of the individuals in the population are specialists in discipline 1, then with probability  $\phi$ , each specialist has a probability  $1 - \pi^K$  of solving the problem and  $\pi^K$  of not solving it. With probability  $1 - \phi$ , the problem is assigned to the other discipline, and no specialist solves it. Thus, the probability of someone in a population of

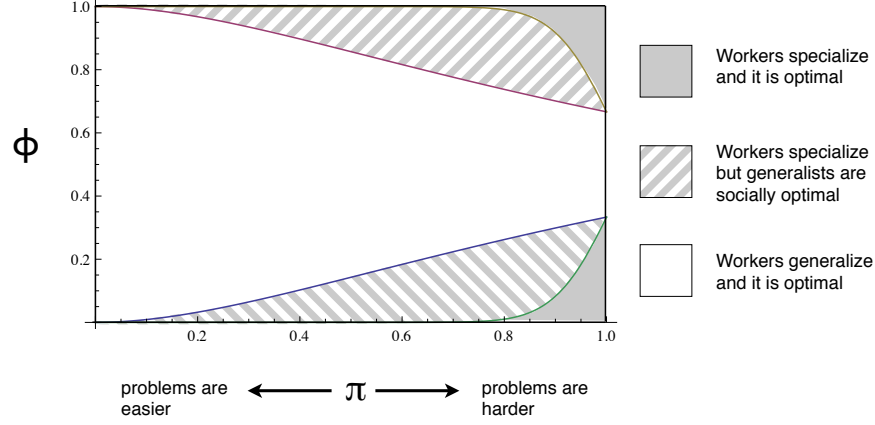


Figure 3.3: Regions of social suboptimality for  $k = 3$ ,  $c = 1$ ,  $N = 10$

discipline 1 specialists solving the problem is

$$\begin{aligned}
 Prob(\text{one of } N \text{ solve it}) &= 1 - Prob(\text{none of } N \text{ solve it}) \\
 &= 1 - [\phi Prob(\text{none solve problem in } d_1) \\
 &\quad + (1 - \phi) Prob(\text{none solve problem in } d_2)] \\
 &= 1 - [\phi Prob(\text{one fails})^N + (1 - \phi) * 1] \\
 &= 1 - [\phi (\pi^K)^N + (1 - \phi) * 1] \\
 &= \phi (1 - \pi^{KN})
 \end{aligned}$$

On the other hand, if they are all generalists, then the probability of at least one solving the problem is

$$\begin{aligned}
 Prob(\text{one of } N \text{ solve it}) &= 1 - Prob(\text{none of } N \text{ solve it}) \\
 &= 1 - (\pi^{K-c})^N \\
 &= 1 - \pi^{N(K-c)}
 \end{aligned}$$

Society is better off with a population of generalists when  $1 - \pi^{N(K-c)} > \phi (1 - \pi^{KN})$ , which is true when  $\phi < \frac{1 - \pi^{N(K-c)}}{1 - \pi^{KN}}$ . However, there is a population of generalists when  $\phi \leq \frac{1 - \pi^{K-c}}{1 - \pi^K}$ . It is always the case that  $\frac{1 - \pi^{K-c}}{1 - \pi^K} \leq \frac{1 - \pi^{N(K-c)}}{1 - \pi^{KN}}$ .

So if  $\frac{1-\pi^{K-c}}{1-\pi^K} < \phi < \frac{1-\pi^{N(K-c)}}{1-\pi^{NK}}$ , then society is better off with a population of generalists, but has a population of specialists.

We can make a similar argument for specialists in discipline 2. Society is better off with a population of generalists when  $1 - \pi^{N(K-c)} > (1 - \phi)(1 - \pi^{KN})$ , which is true when  $\phi > 1 - \frac{1-\pi^{N(K-c)}}{1-\pi^{NK}}$ . However, there is a population of generalists when  $\phi > 1 - \frac{1-\pi^{K-c}}{1-\pi^K}$ . It is always the case that  $1 - \frac{1-\pi^{N(K-c)}}{1-\pi^{NK}} \leq 1 - \frac{1-\pi^{K-c}}{1-\pi^K}$ . So if  $1 - \frac{1-\pi^{N(K-c)}}{1-\pi^{NK}} < \phi < 1 - \frac{1-\pi^{K-c}}{1-\pi^K}$ , then society is better off with a population of generalists, but has a population of specialists. (See Appendix for the same result with  $\delta_1 \neq \delta_2$ )  $\square$

Note that the size of the regions of suboptimality will depend on the number of individuals in the population. As  $N$  increases, the suboptimal regions become larger.

#### 4. An Extension: Problems with Multiple Parts

In the previous section, I showed that barriers to addressing problems in other disciplines can induce problem solvers to diversify their skills. In this section, I consider an extension of the previous model, which highlights a second scenario in which individuals can be incentivized to acquire skills in multiple disciplines: problems with multiple parts. As problems become increasingly complicated, they may be broken down into many different sub-problems. Although in some cases, these subproblems may all be best addressed within a single discipline, in others, different subproblems will be best addressed using different skills. In this section, I show that when problems are *multidisciplinary*—that is, when different parts of a problem are best addressed using different disciplines—then a population of generalists can be sustained.

##### 4.1. Problems With Multiple Parts

As in the previous model, skills in the set  $S$  are divided into two disciplines,  $d_1$  and  $d_2$ . Workers use their skills to address a problem, the nature of which is not known *ex ante*. They will choose to be a specialist or generalist in period 1

to maximize their chances of solving the problem in period 2. But now, suppose each problem consists of two parts,  $y^1$  and  $y^2$ . In order to solve the problem, an individual must solve all parts of the problem.<sup>6</sup> Each part of the problem is addressed independently by the skills in each of the disciplines. Thus, much as before, we can define the parts of the problem by a matrix of probabilities

that each skill will solve the problem. That is,  $y^i = \begin{bmatrix} y_{11}^i & y_{12}^i \\ \vdots & \vdots \\ y_{K1}^i & y_{K2}^i \end{bmatrix}$  where  $y_{kd}^i = H$  if skill  $k$  in discipline  $d$  has a high probability of solving part  $i$  and  $L$  if it has a low probability of solving part  $i$ .

As in the previous section, I will assume that for each part of the problem, skills are independent ( $Prob(y_{kd}^i = H)$  uncorrelated with  $Prob(y_{k'd'}^i = H)$ ) and skills are symmetric within disciplines ( $Prob(y_{kd}^i = H) = Prob(y_{jd}^i = H)$ ).

As before, the probability that a given skill is an  $H$  skill is not known *ex ante*. However, the workers know the expected probability that a skill is an  $H$  skill. I will allow the expected probabilities to vary across parts of the problem—in other words, it is possible that a discipline will be more useful in solving one of the parts of the problem than in solving the other part of the problem. Let  $\delta_d^i$  be the probability that a skill from discipline  $d$  is an  $H$  skill for part  $i$  of the problem. That is,  $\delta_d^i = E[Prob(y_{kd}^i = H)]$ . The matrix  $\delta = \begin{bmatrix} \delta_1^1 & \delta_1^2 \\ \delta_2^1 & \delta_2^2 \end{bmatrix}$  describes a distribution of problems,  $\Delta$ , and is known *ex ante*. An entry in the  $i^{th}$  column of that matrix is the vector of probabilities that a skill in each of the disciplines will be useful for solving part  $i$  of the problem.

We can categorize the problems according to the relative usefulness of the two disciplines in the two parts of the problem. There are two categories for the problems:

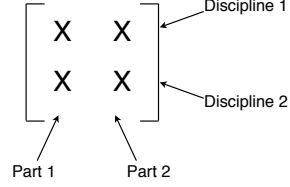
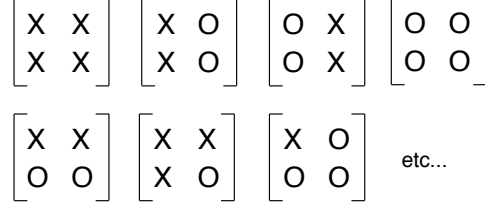
1. One discipline is as or more useful for both parts of the problem:  $\delta_1^i \geq \delta_2^i \forall i$
2. One discipline is more useful for part 1 and the other discipline is more

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<sup>6</sup>This is essentially an adaptation of Kremer's O-ring Theory (Kremer (1993)).



Category 1: One discipline is always as or more useful on all parts



Category 2: Each discipline useful for a different part

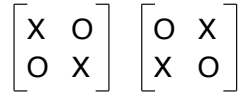


Figure 4.1:

useful for part 2:  $\delta_1^i > \delta_2^i$  and  $\delta_1^j < \delta_2^j$

These categories are illustrated in Figure 4.1.

If a problem falls into the first category, then the results are similar to those obtained in Section 3. In particular, if there are no barriers to working on problems in other disciplines, then all workers will specialize. If a problem falls into the second category, then the results do not resemble any of those already explored. Problems with multiple parts, each of which is best addressed within the context of a different discipline, are often referred to as *multidisciplinary*. Generalists have an advantage in multidisciplinary problems, because they can apply different types of skills to different parts of a problem. For example, suppose a scientist is look at nerve conduction in an organism. That problem may have elements are are best addressed using biological tools, and other elements that are best addressed using physics tools. An individual with both biology and physics skills will have an advantage over someone who is forced to use (for example) physics skills to solve both parts of the problem. The below states that when problems are multidisciplinary, it can be rational to be a generalist, even in the absence of barriers to working in other fields.

More formally, suppose that if a worker uses the “right” discipline for a part of a problem, then there is a probability  $\delta_1$  that a skill in that discipline is

useful ( $\delta_1 = \text{Prob}(y_{kd}^i = H)$  when  $d$  is the right discipline to use for part  $i$  of the problem). If she uses the “wrong” discipline, then there is a probability  $\delta_0$  that a skill in that discipline is useful ( $\delta_1 = \text{Prob}(y_{kd}^i = H)$  when  $d$  is the wrong discipline to use for part  $i$  of the problem). This is without loss of generality, because the only thing that makes a problem multidisciplinary is the ordering of the usefulness of the disciplines. Further, let  $\pi_1 = \delta_1 h + (1 - \delta_1) l$  and  $\pi_0 = \delta_0 h + (1 - \delta_0) l$ . These represent the probability that a skill in the right discipline will not solve a part of a problem and the probability that a skill in the wrong discipline will not solve part of the problem. Note that  $\pi_1 < \pi_0$ .

When the efficacy of the two disciplines is very different ( $\pi_1 \ll \pi_0$ ), then using the right skill for the job has a large effect on the probability of solving the problem as a whole, and it will be rational to obtain skills in multiple disciplines. Figure 4.2 illustrates the region in which individuals choose to be generalists and specialists, and Theorem 4 summarizes the result.

**Theorem 4.** *If skills are independent and symmetric within discipline, and problems multidisciplinary (eg:  $\delta = \begin{bmatrix} \delta_1 & \delta_0 \\ \delta_0 & \delta_1 \end{bmatrix}$  with  $\delta_1 > \delta_0$ ) then there is a set of values of  $\pi_1 = \delta_1 h + (1 - \delta_1) l$  and  $\pi_0 = \delta_0 h + (1 - \delta_0) l$  such that it is individually optimal for workers to be generalists, even when there are no barriers to solving problems in other fields. In particular, workers will become generalists when  $\left(1 - \pi_1^{\frac{K-c}{2}} \pi_0^{\frac{K-c}{2}}\right)^2 > (1 - \pi_1^K) (1 - \pi_0^K)$*

*Proof.* WLOG, consider the case where  $\delta = \begin{bmatrix} \delta_1 & \delta_0 \\ \delta_0 & \delta_1 \end{bmatrix}$  with  $\delta_1 > \delta_0$ . A specialist in discipline  $i$  will have  $K$  skills in discipline  $i$ . The expected probability that her skills will solve *both* parts of the problem is  $E[P(\text{success on part 1})] * E[P(\text{success on part 2})]$ , which is  $(1 - \pi_1^K) (1 - \pi_0^K)$  where  $\pi_1 = \delta_1 h + (1 - \delta_1) l$  and  $\pi_0 = \delta_0 h + (1 - \delta_0) l$ .

A generalist will have skills in both disciplines. In this case, it will be optimal for a generalist to split her skills evenly between the two disciplines, and she will obtain  $\frac{K-c}{2}$  skills in each. The expected probability that she will solve both

Equilibrium Skill Acquisition as a Function of  $\pi_1$  and  $\pi_0$   
(Two Part Problem with  $K=3$ ,  $c=1$ )

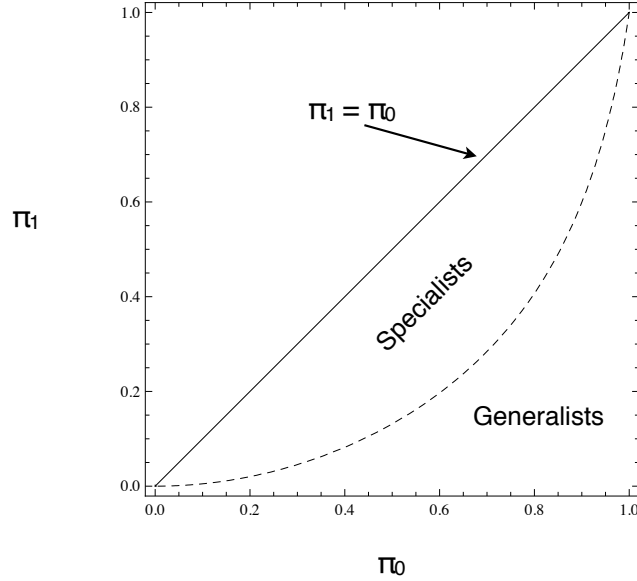


Figure 4.2: Equilibrium skill acquisition decisions when problems are multidisciplinary, and  $k = 3$  and  $c = 1$ .

parts of the problem is  $\left(1 - \pi_1^{\frac{K-c}{2}} \pi_0^{\frac{K-c}{2}}\right)^2$ .

Thus, individuals choose to generalize, when  $\left(1 - \pi_1^{\frac{K-c}{2}} \pi_0^{\frac{K-c}{2}}\right)^2 > (1 - \pi_1^K)(1 - \pi_0^K)$ .<sup>7</sup> This region, as a function of  $\pi_1$  and  $\pi_0$ , is illustrated in Figure 4.2 for  $K = 3$  and  $c = 1$ . The boundary of this region is defined by the equation  $\pi_1^K + \pi_0^K = (\pi_1 \pi_0)^{\frac{K-c}{2}} - 2(\pi_1 \pi_0)^{K-c} + (\pi_1 \pi_0)^K$ .  $\square$

As would be expected, the region where individuals specialize shrinks as the costs to generalizing ( $c$ ) become smaller, relative to the individual's total

<sup>7</sup>Note that when  $\delta_1 = \delta_0$ , we have a case that fits into the first category in the taxonomy of problem distributions in Figure 4.1. Since  $\delta_1 = \delta_0 \implies \pi_1 = \pi_0$ , we can use this calculation to verify the claim made above that in the case where skills are symmetric, the results are the same as in Section 3.

capacity for learning new skills ( $M = K + c$ ).

## 5. Conclusion

Being a generalist is costly. Every new area of expertise comes at considerable fixed cost, in the form of a new literature, new jargon, and new basic ideas. However, there are clearly a large (and growing) number of individuals in research communities who choose to do so. This raises the question of whether that decision is ever individually rational? And is there a reason to believe that fewer people choose to be generalists than is socially optimal?

This paper suggests that being a generalist can be a rational decision under particular conditions. In particular, obtaining a broad range of skills is rational if there are significant barriers to working on questions in fields with which one is unfamiliar. Those who pay the initial price of learning the jargon and literature of a new field reap the benefits in the form of a larger pool of problems to solve. It can also be rational to be a generalist if problems are multidisciplinary—that is, if different parts of a problem are best addressed using skills in different disciplines. Moreover, because individuals bear the costs of becoming generalists, we will tend to have fewer of them than is optimal from a societal standpoint. This potential market failure means that in some cases, it is optimal for funding agencies and private organizations to subsidize individuals in their efforts to diversify their skills and promote interdisciplinary researchers. However, it is unclear whether our current situation is one in which such funding is required. More careful consideration of this question is a good candidate for further work.

There are several elements of this model that suggest directions for future research. It would be interesting to consider a case where individuals differ in their innate capacity for learning skills. This might provide some insight into what types of individuals choose to become generalists. Incorporating collaboration would be another particularly interesting extension. Collaboration has always been an important part of problem solving and innovation, and it has only become more important over time (see, among others, Laband and Tollison

(2000), Acedo et al (2006), and Goyal et al (2006)). There is reason to believe that in a collaborative context, the advantage to generalists would be enhanced, because generalists could connect specialists in different fields.

On a more general level, there is much to be gained from a better understanding of specialization decisions. Research universities, government organizations such as NASA, and private enterprises ranging from Genentec to Google are reliant on the skills of individual problem solvers. The decisions these individuals make about the breadth skills they obtain have an undeniable effect on the rate of innovation. However, we still have only a limited understanding of the what drives those skill acquisition decisions, and what distinguishes the role of specialists and generalists in problem solving. Better theoretical models of these decisions have the potential to greatly enhance our understanding of this important aspect of such organizations.

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## Appendix

Theorem 5 is the equivalent of Theorem 1, and states that if individuals can work on any available problem, then there is no advantage to being a generalist.

**Theorem 5.** *If skills are independent and symmetric within discipline, and workers can work on any available problem, then no worker will ever want to be a generalist and the equilibrium population will contain only specialists.*

*Proof.* As above, the *ex ante* probability that a specialist in discipline  $i$  will be able to solve a problem from a given distribution,  $\Delta$ , is

$$\begin{aligned} E[P(S_i)] &= 1 - (\delta_i h + (1 - \delta_i) l)^K \\ &= 1 - \pi_i^K \end{aligned}$$

where  $\pi_i = (\delta_i h + (1 - \delta_i) l)$ .

WLOG, suppose  $\delta_1 > \delta_2$ . Since  $h < l$ , this means that  $\pi_1 < \pi_2$  and  $E[P(S_1)] > E[P(S_2)]$ . Thus, to determine whether any individual will generalize, I need to compare  $E[P(S_1)]$  to  $E[P(G)]$ .

The *ex ante* probability that a generalist with  $x$  skills in discipline 1, and  $K - c - x$  skills in discipline 2 solves a problem from a given distribution,  $\Delta$ , is

$$\begin{aligned} E[P(G)] &= 1 - (\delta_1 h + (1 - \delta_1) l)^x (\delta_2 h + (1 - \delta_2) l)^{K-c-x} \\ &= 1 - \pi_1^x \pi_2^{K-c-x} \end{aligned}$$

Since  $\pi_1 < \pi_2$ ,  $E[P(G)]$  is strictly increasing in  $x$ . This means that a generalist will set  $x = K - c - 1$  and  $E[P(G)] = 1 - \pi_1^{K-c-1} \pi_2$ , which is clearly less than  $E[P(S_1)] = 1 - \pi_1^K$ .  $\square$

Theorem 6 is a generalized version of Theorem 2, and states the parameter range in which individuals will choose to diversify their skills when there are barriers to working interdisciplinarily.

**Theorem 6.** *If skills are independent and symmetric within discipline, and there are barriers to working on problems in other disciplines, then there is a*

range of values for  $\phi$  (the fraction of problems assigned to discipline 1) for which individuals will generalize.

In particular, the ranges are as follows:

If  $\delta_1 = \delta_2 = \delta$ , workers will obtain  $K - c$  skills spread across the two disciplines when  $1 - \frac{1-\pi^{K-c}}{1-\pi^K} \leq \phi \leq \frac{1-\pi^{K-c}}{1-\pi^K}$ ,  $K$  skills in discipline 1 when  $\phi > \frac{1-\pi^{K-c}}{1-\pi^K}$ , and  $K$  skills in discipline 2 when  $\phi < 1 - \frac{1-\pi^{K-c}}{1-\pi^K}$ .

If  $\delta_1 > \delta_2$ , then workers will obtain  $K - c - 1$  skills in discipline 1 and one skill in discipline 2 when  $1 - \left( \frac{1-\pi_1^{K-c-1}\pi_2}{1-\pi_2^K} \right) \leq \phi \leq \frac{1-\pi_1^{K-c-1}\pi_2}{1-\pi_1^K}$ ,  $K$  skills in discipline 1 when  $\phi > \frac{1-\pi_1^{K-c-1}\pi_2}{1-\pi_1^K}$ , and  $K$  skills in discipline 2 when  $\phi < 1 - \left( \frac{1-\pi_1^{K-c-1}\pi_2}{1-\pi_2^K} \right)$ .

If  $\delta_2 > \delta_1$ , then workers will obtain  $K - c - 1$  skills in discipline 2 and one skill in discipline 1 when  $1 - \left( \frac{1-\pi_2^{K-c-1}\pi_1}{1-\pi_1^K} \right) \leq \phi \leq \frac{1-\pi_2^{K-c-1}\pi_1}{1-\pi_2^K}$ ,  $K$  skills in discipline 1 when  $\phi > \frac{1-\pi_2^{K-c-1}\pi_1}{1-\pi_1^K}$ , and  $K$  skills in discipline 2 when  $\phi < 1 - \left( \frac{1-\pi_2^{K-c-1}\pi_1}{1-\pi_2^K} \right)$ .

*Proof.* In this case, the *ex ante* probability that a problem is solved by a specialist is  $\phi(1 - \pi_1^K)$  for a specialist in discipline 1 and  $(1 - \phi)(1 - \pi_2^K)$  for a specialist in discipline 2. Since generalists can work on problems in both disciplines, their expected probability of solving the problem is  $1 - \pi_1^x \pi_2^{K-c-x}$  where  $x$  is the number of skills the generalist chooses to acquire in discipline 1. First, suppose  $\delta_1 > \delta_2$ . Since  $h < l$ , this means that  $\pi_1 < \pi_2$  and  $E[P(G)]$  is strictly increasing in  $x$ . Thus, a generalist will choose a minimal number of skills in the less useful discipline, and  $E[P(G)] = 1 - \pi_1^{K-c-1} \pi_2$ .

An individual will generalize if  $E[P(S_1)] < E[P(G)]$  and  $E[P(S_2)] < E[P(G)]$ . Setting  $\phi(1 - \pi_1^K) < 1 - \pi_1^{K-c-1} \pi_2$  implies that  $\phi \leq \frac{1-\pi_1^{K-c-1}\pi_2}{1-\pi_1^K}$ . Setting  $(1 - \phi)(1 - \pi_2^K) < 1 - \pi_1^{K-c-1} \pi_2$  implies that  $1 - \frac{1-\pi^{K-c}}{1-\pi^K} \leq \phi$ . We can verify that in the appropriate ranges, individuals choose to specialize. The result follows immediately. The proof for  $\delta_2 > \delta_1$  is similar. For the proof when  $\delta_1 = \delta_2$ , see Theorem 2.  $\square$

Finally, Theorem 7 is the generalization of Theorem 3. It states that there is a parameter region in which individuals choose to specialize, but society would



prefer to have at least a few generalists.

**Theorem 7.** *If skills are independent and symmetric within discipline, and there are barriers to working on problems in other disciplines, then there is a range of values for  $\phi$  (the fraction of problems assigned to discipline 1) such that generalists are underprovided in the equilibrium population of problem solvers.*

*In particular, generalists are underprovided in the following ranges:*

*If  $\delta_1 = \delta_2$ , then generalists are underprovided when  $\frac{1-\pi^{K-c}}{1-\pi^K} < \phi < \frac{1-\pi^{N(K-c)}}{1-\pi^{NK}}$  or  $1 - \frac{1-\pi^{N(K-c)}}{1-\pi^{NK}} < \phi < 1 - \frac{1-\pi^{K-c}}{1-\pi^K}$*

*If  $\delta_1 > \delta_2$ , then generalists are underprovided when  $\frac{1-\pi_1^{K-c-1}\pi_2}{1-\pi_1^K} < \phi < \frac{1-\pi_1^{N(K-c-1)}\pi_2}{1-\pi_1^{NK}}$  or  $1 - \frac{1-\pi_1^{N(K-c-1)}\pi_2}{1-\pi_2^{NK}} < \phi < 1 - \frac{1-\pi_1^{K-c-1}\pi_2}{1-\pi_2^K}$*

*If  $\delta_2 > \delta_1$ , then generalists are underprovided when  $\frac{1-\pi_1\pi_2^{K-c-1}}{1-\pi_1^K} < \phi < \frac{1-\pi_1\pi_2^{N(K-c-1)}}{1-\pi_1^{NK}}$  or  $1 - \frac{1-\pi_1\pi_2^{N(K-c-1)}}{1-\pi_2^{NK}} < \phi < 1 - \frac{1-\pi_1\pi_2^{K-c-1}}{1-\pi_2^K}$*

*Proof.* First, suppose that  $\delta_1 > \delta_2$ . The probability that at least one of the  $N$  problem-solvers in the population solves the problem is  $1 - \text{Prob}(\text{none of them do})$ .

If all of the individuals in the population are specialists in discipline 1, then every individual has probability  $\phi$  of a problem occurring in her discipline. In that case, each specialist in discipline has a probability  $1 - \pi_1^K$  of solving the problem and  $\pi_1^K$  of not solving it. With probability  $1 - \phi$ , the problem is assigned to the other discipline, and no specialist solves it. Thus, the probability of someone in a population of specialists solving the problem is

$$\begin{aligned}
\text{Prob}(\text{one of } N \text{ solve it}) &= 1 - \text{Prob}(\text{none of } N \text{ solve it}) \\
&= 1 - [\phi \text{Prob}(\text{none solve problem in } d_1) + (1 - \phi) \text{Prob}(\text{none solve problem in } d_2)] \\
&= 1 - [\phi \text{Prob}(\text{one fails})^N + (1 - \phi) * 1] \\
&= 1 - [\phi (\pi_1^K)^N + (1 - \phi) * 1] \\
&= \phi (1 - \pi_1^{KN})
\end{aligned}$$

Through a similar argument, if everyone in the population is a specialist in discipline 2, then the probability that someone in the population solves the problem is  $(1 - \phi) (1 - \pi_2^{KN})$ .

If everyone in the population is a generalists, then the probability of at least one person in solving the problem is

$$\begin{aligned}
\text{Prob (one of N solve it)} &= 1 - \text{Prob (none of N solve it)} \\
&= 1 - (\pi_1^{K-c-1} \pi_2)^N \\
&= 1 - \pi_1^{N(K-c-1)} \pi_2^N
\end{aligned}$$

Society is better off with a population of generalists than a population of discipline 1 specialists when  $1 - \pi_1^{N(K-c-1)} \pi_2^N > \phi (1 - \pi_1^{KN})$ , which is true when  $\phi < \frac{1 - \pi_1^{N(K-c-1)} \pi_2^N}{1 - \pi_1^{KN}}$ . However, there is a population of generalists when  $\phi \leq \frac{1 - \pi_1^{K-c-1} \pi_2}{1 - \pi_1^K}$ . It is always the case that  $\frac{1 - \pi_1^{K-c-1} \pi_2}{1 - \pi_1^K} \leq \frac{1 - \pi_1^{N(K-c-1)} \pi_2^N}{1 - \pi_1^{NK}}$ . Thus, if  $\frac{1 - \pi_1^{K-c-1} \pi_2}{1 - \pi_1^K} < \phi < \frac{1 - \pi_1^{N(K-c-1)} \pi_2^N}{1 - \pi_1^{NK}}$ , then society is better off with a population of generalists, but has a population of specialists.

Through a similar argument, society is better off with a population of generalists than a population of discipline 2 specialists when  $1 - \pi_1^{N(K-c-1)} \pi_2^N > (1 - \phi) (1 - \pi_2^{KN})$ , which is true when  $\phi > 1 - \frac{1 - \pi_1^{N(K-c-1)} \pi_2^N}{1 - \pi_2^{KN}}$ . However, there is a population of generalists when  $\phi \leq 1 - \frac{1 - \pi_1^{K-c-1} \pi_2}{1 - \pi_2^K}$ . It is always the case that  $1 - \frac{1 - \pi_1^{N(K-c-1)} \pi_2^N}{1 - \pi_2^{NK}} \leq 1 - \frac{1 - \pi_1^{K-c-1} \pi_2}{1 - \pi_2^K}$ . Thus, if  $1 - \frac{1 - \pi_1^{N(K-c-1)} \pi_2^N}{1 - \pi_2^{NK}} < \phi < 1 - \frac{1 - \pi_1^{K-c-1} \pi_2}{1 - \pi_2^K}$ , then society is better off with a population of generalists, but has a population of specialists.

The proof for  $\delta_2 > \delta_2$  is similar. See the proof of Theorem 3 for the case where  $\delta_1 = \delta_2$ .  $\square$